The Kootenay-Rossland Power Transmission—Concluded.

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THE JOURNAL OF ELECTRICITY.

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The Kootenay-Rossland Power Transmission.

BY GEO. P. LOW.

[CONCLUDED.]

THE ROSSLAND SUB-STATION.

THE transmission lines enter the sub-station at Rossland through portholes lined with eight-inch terra cotta piping similar to those provided at the power house. As one enters the door of the sub-station the standard General Electric lightning arresters used are placed on a marble board in a corner at the left as shown in the floor plan appearing on page 86. The choke coils used are an innovation in that each consists of a core twelve inches or so in length turned in the center of a stick of kiln dried and well filled timber about five inches square, by from six to eight feet long. About this core insulated wire is wound until the space is filled so that the choke coil thus formed resembles an exaggerated form of spark coil with its terminals carried out to the respective ends of the timber on which it is wound, these timber ends being strapped to the top of high tension insulators through which the choke coil is cut into the line. Such choke coils are placed in every line, not only at the sub-station but at every power service. At present the Rossland sub-station contains but six 250-kilowatt step-down transformers, although six others, each of equal capacity, are being installed with the new 1500-kilowatt generator. The line wires are carried to the high tension switchboard at the rear of the station on high tension insulators supported by framings that hang from the roof girders, and the usual facilities are provided to afford safety and celerity in the handling of both the high and low tension sides of the transformers. These latter are of the same type and size as those installed at the power house, with the exception that the primaries take either 9600 or 16,600 volts, according to whether connected in delta or Y, while the secondaries deliver 2200 volts in three-phase current, which is the potential used on all the lighting and power distributing circuits in and about Rossland.

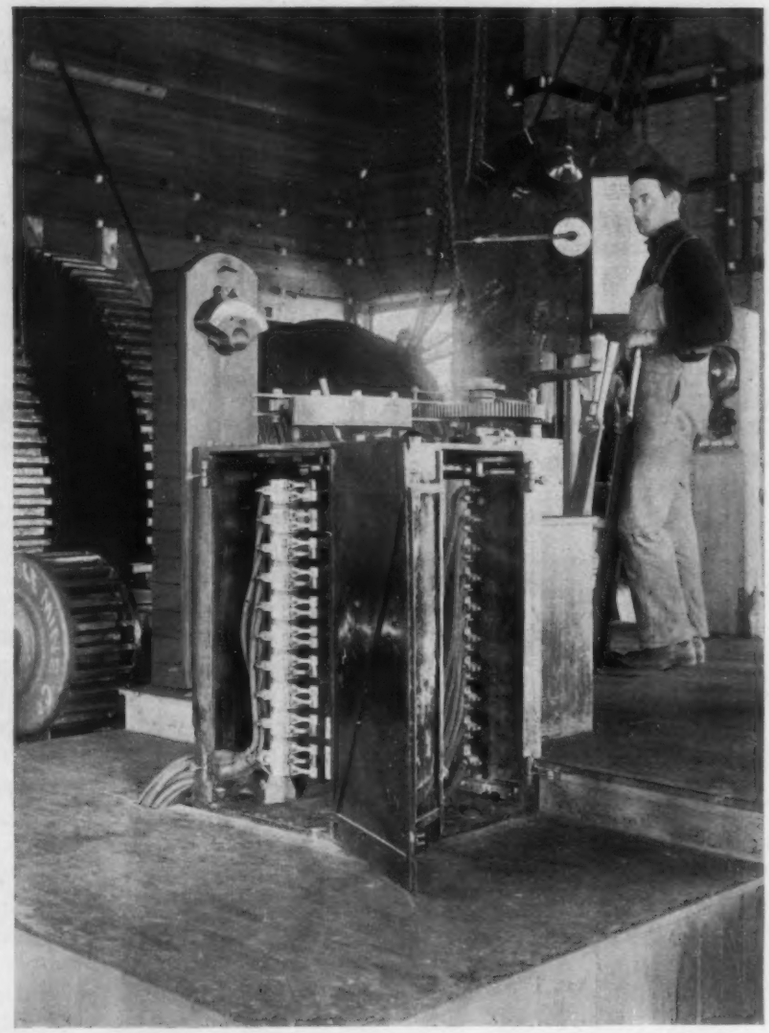


FIGURE 22.—VIEW OF CONTROLLER FOR INDUCTION MOTOR AT WAR EAGLE MINE.

Here may be explained, through the accompanying cuts presenting the floor plan, end and side elevations of the sub-station at Rossland, the very meritorious method which the electrical engineer of the West Kootenay company has devised for applying the air blast to the transformers at the power house and at the Rossland sub-station. As in the power house, the blast is supplied by three sixty-inch blowers each driven by belting from a two horse-power 100-volt induction motor. Instead of carrying this air blast to the transformers through small

air ducts as is usually done, the engineer of the Kootenay plant has provided subways large enough for a man to enter and move about in. The manner in which the blowers supply air to these subways is shown in the end elevation of the sub-station, while the subways themselves, as is shown in the side elevation, extend in line with and directly under each row of step-down transformers. The

FIGURE 14.—THE SUB-STATION AT ROSSLAND.

idea of this arrangement will be understood when it is stated that each week the transformers are cut out of service one by one and the air ducts in them are each and every one examined and cleaned by a man who enters the subway in order that he may have access to the lower end of the air ducts in the transformer. His work in cleaning the transformers is facilitated by the use of compressed air, which is obtained in both the power house and the sub-station from a single drill compressor driven by an induction motor. It is safe to say that so long as this method of transformer examination and cleaning is

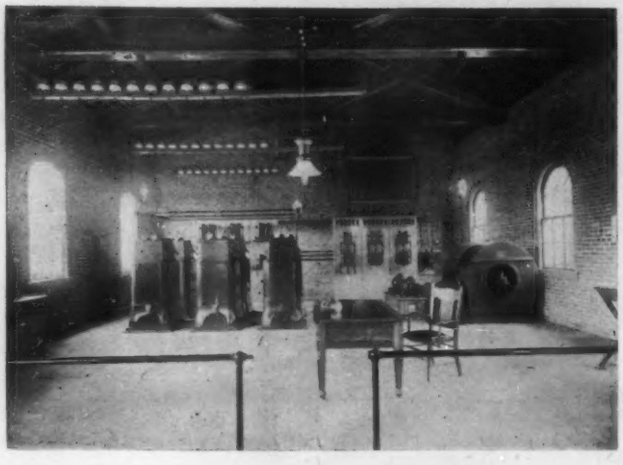


FIGURE 15.—INTERIOR OF SUB-STATION AT ROSSLAND.

faithfully carried out the Kootenay transmission will never lose a transformer from the choking of its air ducts. Slides for regulating the amount of air to be delivered to each transformer are provided and of course the subway is always air tight and the man who cleans the transformers is under the increased atmospheric pressure of the air blast while at his work.

The photograph showing the interior of the sub-station was taken shortly after the plant started operations and since then important additions have been made. The distributing switchboard at the right in the rear has had new panels added to it to accomodate other circuits. The third blower has been added and immediately in front of it, as shown in the floor plan of the sub-station in Figure 16, has been placed the induction regulator by means of which the potential of the outgoing lighting service is controlled by the sub-station attendant independent of the power house.

This is a new device of the General Electric Company, bearing the designation "type I. R. T. class 4–20–60 form A." It is wound for seventy amperes per phase at 2200 volts and has a range of 220 volts in either direction. It is described as consisting of an induction motor with a vertical shaft, which is connected through bevel and worm gearing to the shaft of a pilot motor placed on top of the case so that the rotor of the induction regulator may be

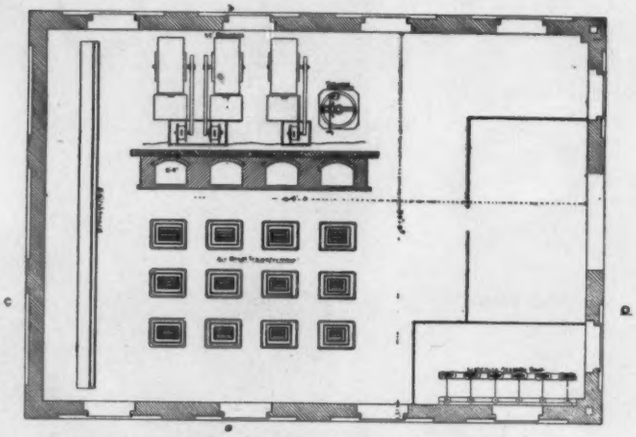


FIGURE 16.—FLOOR PLAN OF SUB-STATION AT ROSSLAND.

made to turn a given arc in either direction and in so turning raises or lowers the electromotive-force in the primary mains passing through the stator windings as desired. The pilot motor is manipulated from a simple double-pole, double-throw reversing switch placed on the switchboard; and this motor too is an induction motor. All details of this novel regulator together with those of the limiting switch placed thereon are given in Figure 20. At present this regulator is used only on the lighting circuits, nor is its use contemplated on the power service.

All the electric lighting in Rossland, in both arc and incandescent services, is rendered from alternating circuits, and indeed the only use to which direct currents are put in the Kootenay plant is for the excitation of generators and synchronous motors. The electric lighting load reaches a maximum of nearly 400 horse-power. Enclosed alternating arc lamps are used exclusively and these are burned from the 110-volt commercial circuits. The ultimate distribution is on the Edison three-wire system through the use of type H transformers taking either 1400 or 2080 volts on the primary and delivering

230 volts across the outsides of three-wire service. The utmost care has been exercised in preserving the balance on the three-wire distribution circuits as well as in balancing the primaries of the commercial transformers on the three-wire, three-phase, 2200-volt circuits, and this balancing has been carried out so well that it has never been observed that the phases of the 2200-volt circuits have been more than 10 amperes out of balance.

As stated heretofore, the principal interest in the Kootenay-Rossland transmission centers in its application of electric power for mining and milling purposes, the most notable installations being in the properities of the War Eagle Mining and Development Company, the British Columbia Bullion Extraction Company, the British American Corporation, and the Gertrude, Big Three and Iron Mask mines. These six properties alone consume about seventeen hundred horse-power in the operation of hoists, compressors, crushers, conveyers, ventilating blowers and in electrolytic work. The bulk of this power is delivered by induction motors, for as a general rule, synchronous motors have been applied only to the driving of compressors.

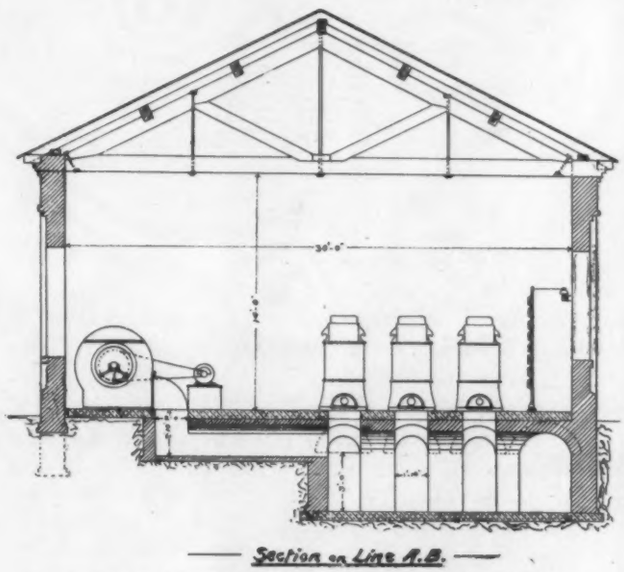


FIGURE 17.—END ELEVATION OF SUB-STATION AT ROSSLAND.

The initial illustration gives a general view of the controller of the War Eagle hoist which will be seen to be a standard General Electric induction motor. It is a three-phase equipment operated at 2300 volts, has twenty-four poles and delivers three hundred horse-power at three hundred revolutions per minute. Its technical designation is, therefore, "I 24–300–300 form A." The rotor shaft is geared to a Ledgerwood type double drum hoist through double reduction gearing, having a ratio of reduction of 300 to 40. The War Eagle shaft is at present down a little beyond the 600-foot level and the maximum load raised amounts to eight tons including the load, cage and rope, the speed being 720 feet per minute for this load.

Interest of course centers in the method of speed control, each technical detail of which is fully shown in the accompanying photographs and drawings. Secondary control is used exclusively; that is, no effort whatever is made to control the primary current, while the secondary current, or that induced in the rotor circuit, is varied by the introduction of external resistance. The controller

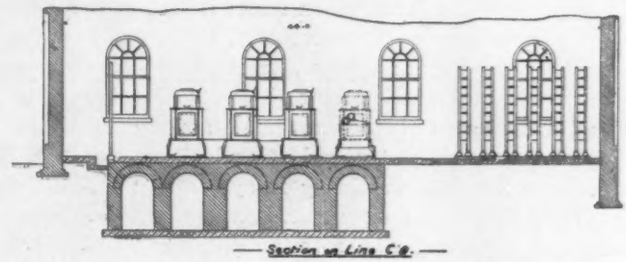


FIGURE 18.—SIDE ELEVATION OF SUB-STATION AT ROSSLAND.

proper, shown in Figure 22 is a duplex one inasmuch as the movement of the controller handle manipulates both the primary and secondary circuits of the motor, the former for making, breaking and reversing and the latter for the control of the variable external resistance. The controller on the high tension or stator side operates in a bath of mineral oil. The secondary windings are led to three collector rings placed on the shaft with the rotor, and upon these rings bear carbon brushes which cover about 90 degrees of the surface of the rings, this being a necessary procedure because of the heavy ampereage to be taken off. The maximum secondary electromotive force obtained is in the neighborhood of seventy volts. From the rotor brushes the current is carried to the low tension side of the controller through which resistance may be cut in or out of the rotor windings in ten steps. The resistance consists of cast iron grids arranged upon a large slate resistance board as shown in Figures 25 and 26. With the maximum load of eight tons gross at a speed

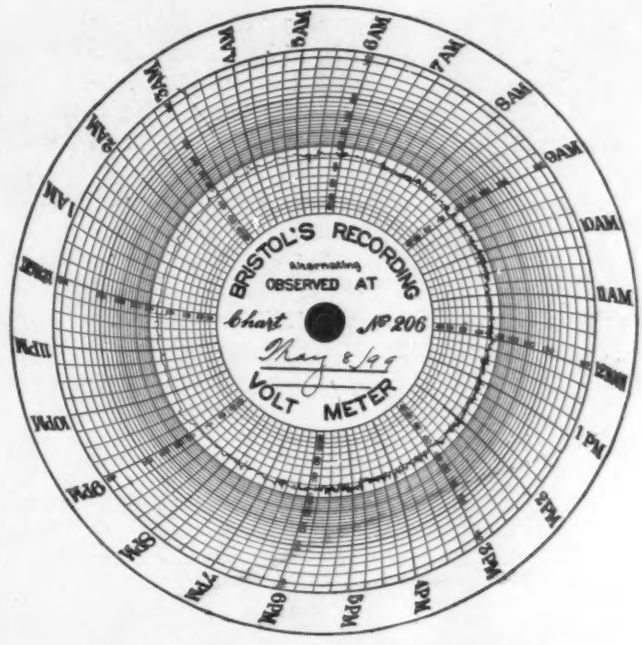


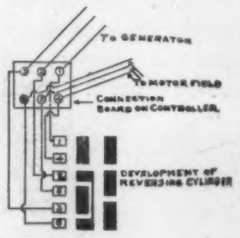
FIGURE 19.—TYPICAL CHART OF VOLTAGE REGULATION.

of 720 feet per minute the current reaches a maximum of 110 amperes per phase, dropping back to 90 amperes as the load decreases by the reason of the cage nearing the surface. With a load of men the maximum current is 70 amperes per phase.

The principle under which variable speed is attained in the operation of this induction motor is found in the fact that while in the synchronous motor, exact synchronism between the motor and generator must always be maintained, yet the induction motor is so constituted as to be nearly independent of any magnetic slippage that may exist between its stator and rotor. When under full speed the motor is practically in synchronism with the generator, but with the generator speed constant a variable speed in the motor is best attained by the introduction of methods that will provide variable slippage as desired, for the greater the slippage the slower will be the speed of the rotor. The equipment at the War Eagle hoist is so controlled that the speed of the motor may be varied from forty revolutions or less per minute to its full speed of three hundred revolutions.

As will be seen in Figure 22, the high and low tension controllers are geared together, this being done in such a manner that both are actuated at proper intervals by the manipulation of a single controller handle. The only function of the electrical equipment is that of hoisting, for as the cages are balanced one against the other it is the rule that power is applied for either direction of rotation. Braking is done through the application of band brakes by means of the hand levers shown in the illustration on the next page.

The subjoined diagram of circuit connections shows the development of the reversing cylinder as applied to the high tension controller. The head board of this controller has six terminal lugs, those numbered 1, 2 and 3 being for the service leads, while those numbered 4, 5 and 6 are carried to the motor. The controller applies the full line potential of 2300 volts to the stator, and it serves not only as a make and break switch but also as a pole changer for reversing. The short circuiting of terminals 1 to 4, 2 to 6, and 5 to 3, causes a given direction of rotation, while the short circuiting of terminals 1 to 4, 2 to 5, and 3 to 6 causes an opposite direction of rotation, all as shown in the attached circuit diagram. Mineral seal or any high grade transformer oil may be used for the bath for this high tension controller, which gives perfect satisfaction in operation.



The connections of the circuits by means of which external resistance is cut in and out of circuit with the rotor windings through the low tension controller are outlined in Figure 23, and in Figure 27 is given the assembly diagram of the stationary cast iron resistance as mounted on the slate resistance board shown in front and back views in Figures 25 and 26. It must be understood that the terminals at the bottom of the slate panels appearing in the upper portion of Figure 23 are the same as those shown at the bottom of Figure 27. The resistance strips shown so clearly in Figure 26 consist of cast iron grids, each in three waves, having a sectional area of about ⅛ by ⅝ inches and which have a running length of about sixty inches. These grids stand out from the board

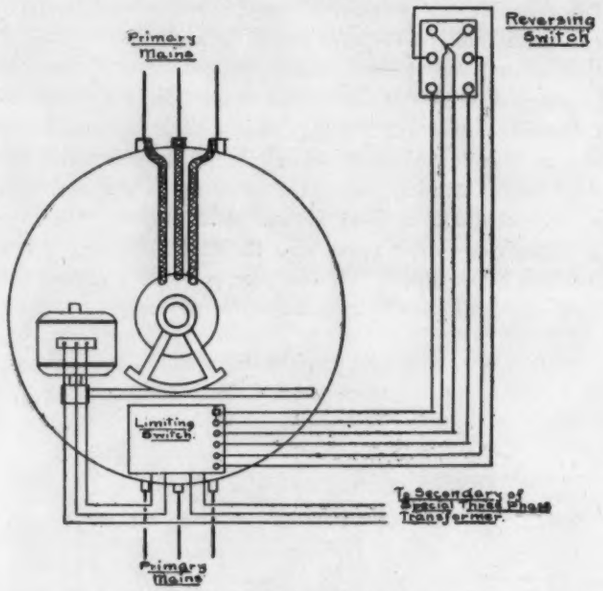


FIGURE 20.—CONNECTIONS OF INDUCTION REGULATOR.

about 14 inches and they are in 23 vertical rows by 18 horizontal ones, and while the average cross section is as given, it varies slightly above and below that figure according to the ampereage carried.

Reverting to the scheme of low tension controller and resistance switch-board connections outlined in Figure 23, the leads from the slip rings on the shaft of the motor are carried to three sets of contact plates placed on the controller cylinder in ordinary arrangement, and upon these contact plates play the contact fingers which carry current successively to the resistance. Three posts are erected in the controller,

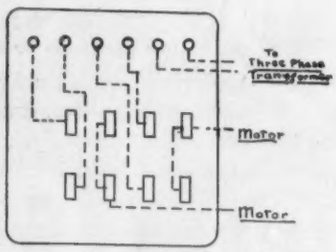


FIGURE 21.—CONNECTIONS OF LIMITING SWITCH.

each of which carries a set of ten contact fingers and two of the sets are shown in Figure 22. As stated, the maximum potential broken by the low tension controller is about seventy volts and the sparking is inconsequential.

One who is interested could spend hours in watching the operation of this hoist. It is easily handled by one man who finds himself with much less to do than has the motorman on an electric railway. In fact, the operation of the War Eagle hoist finds greater resemblance to street railway practice than one would imagine. The controller is manipulated with the same ease and celerity that attends the handling of a street railway controller, and it is more

simple than the modern street railway controller in one regard, and that is the fact that reversal is accomplished in the War Eagle controller by the moving of the controller handle in a reverse direction rather than in the throwing of a special lever. At times when men are on the cage the hoist is "kicked" along by the momentary application of power to the motor, which enables it to be run at much slower speed even than that possible with the controller on the first notch. At other times in hoisting ore, a dead load of five tons of which is al-

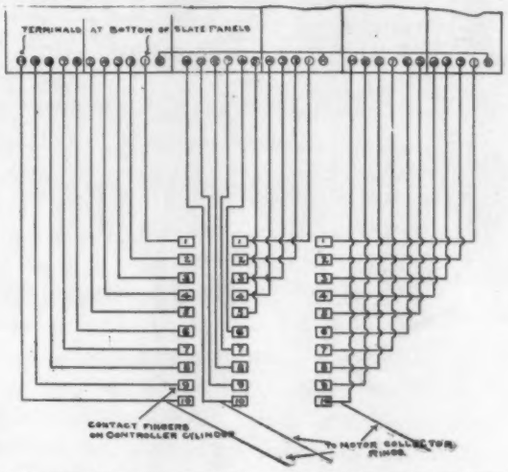


FIGURE 23.—CONNECTIONS OF INDUCTION HOIST MOTOR AND CONTROLLER.

most always carried, the motor will be brought up to speed in a very few seconds and this without any abnormal inrush of current, for, as stated, during the writer's observations of the operation of the equipment under all conditions of service the motor intake did not exceed 110 amperes per phase. The motor has an efficiency of 92 per cent. and a full load power factor of 88 per cent., while at the slowest speed the power factor may drop to possibly between sixty and seventy per cent., but of this last statement no direct data is available at present. Current for the operation of the entire War Eagle equipment is sold by contract; *i. e.* on flat rates.

The next feature of interest in the electrical installation at the War Eagle mine is found in the 300-kilowatt synchronous motor operating the 40-drill compressor il-

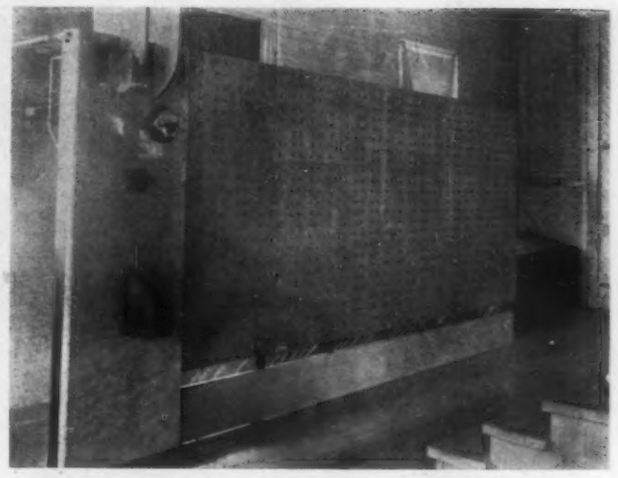


FIGURE 25.—FRONT VIEW OF EXTERNAL RESISTANCE BOARD.

lustrated in Figure 28. Three-phase current at 2300 volts is applied to this motor which runs at 200 revolutions per minute. It is of the revolving armature type, has thirty-six poles and, consequently, bears the designation "A P 36–300–200." A General Electric multipolar exciter, not shown in the illustration, is driven from a large pulley on the free end of the motor shaft, and this exciter has an output of nine kilowatts at 125 volts when operated at 1450 revolutions per minute. The compressor, which is of a double duplex type, is driven through independent ropes applied direct as shown in the illustration.

The method originally installed for starting the synchronous motor is also shown in the illustration given and it consisted of a thirty horse-power induction motor belted

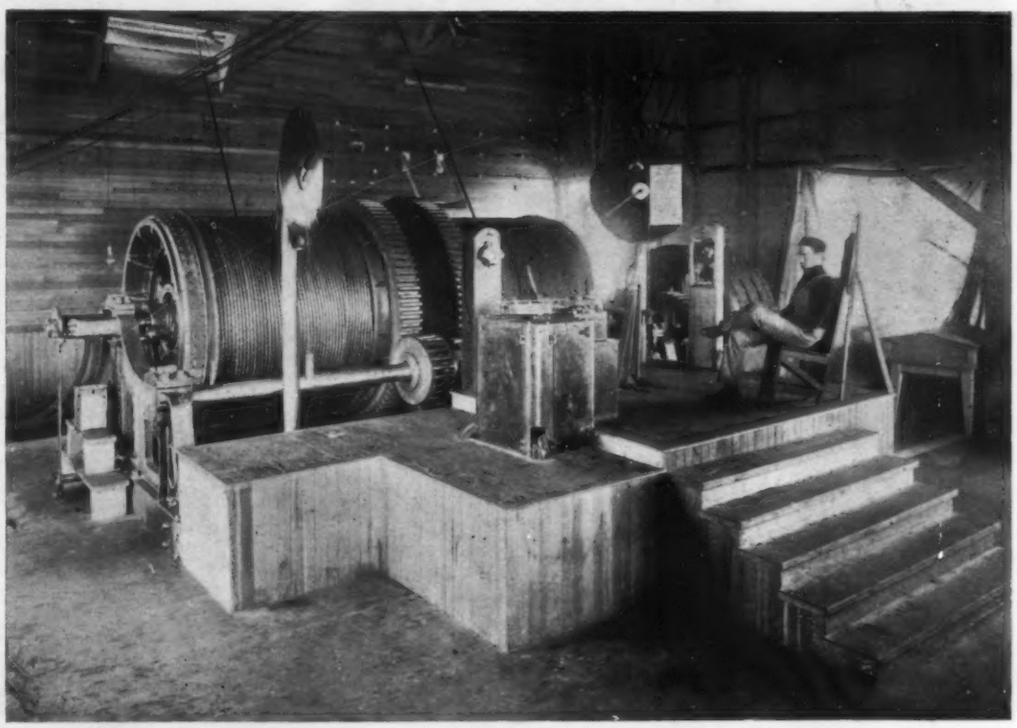


FIGURE 24.—GENERAL VIEW OF INDUCTION HOISTS AT WAR EAGLE MINE.

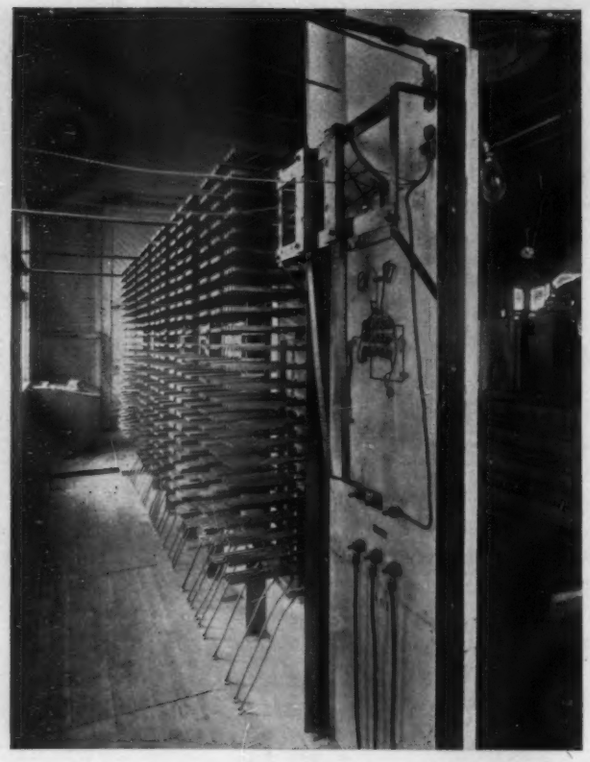


FIGURE 26.—BACK VIEW OF EXTERNAL RESISTANCE BOARD.

to a counter shaft through a friction clutch, this shaft carrying a spur gear by means of which the armature was brought up to speed. It can not be said that this equipment has been satisfactory, although it is in practical operation. The difficulties in its use rest first in the fact that in bringing the armature up to synchronism the compressor must, as well, be brought up to speed; and second, the 30 horse-power motor is too small for the duty required. It takes most exactly eight minutes to bring the motor up to synchronism, in doing which the

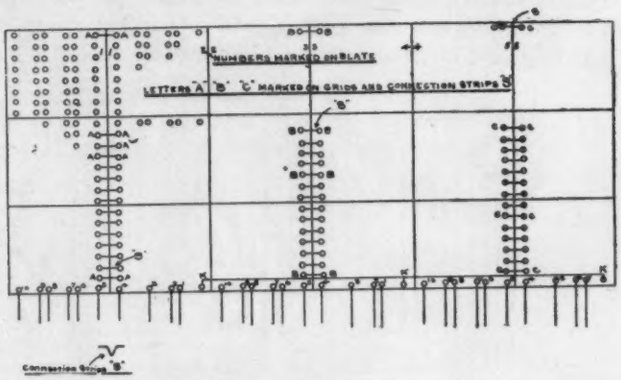


FIGURE 27.—ASSEMBLY DIAGRAM OF STATIONARY CAST IRON RESISTANCE.

30 horse-power induction motor delivers from 120 to 130 horse-power, and, incidentally, has its temperature raised to a point somewhere above that conducive to a ripe old age. Although the small motor was still in service at the time of the writer's visit to the mine, it was shortly to be replaced by one having more than double its capacity. It should be stated in justice to the engineer of the Kootenay company that the starting device here discussed was not of his design or sanction. With the exception of the time consumed in starting, the equipment gives the best of satisfaction. A number of small motors ranging up to 20 horse-power in capacity are used in and about the War Eagle mine for ventilating purposes, driving conveyors, etc., and all these motors are of the induction type except that on the compressor.

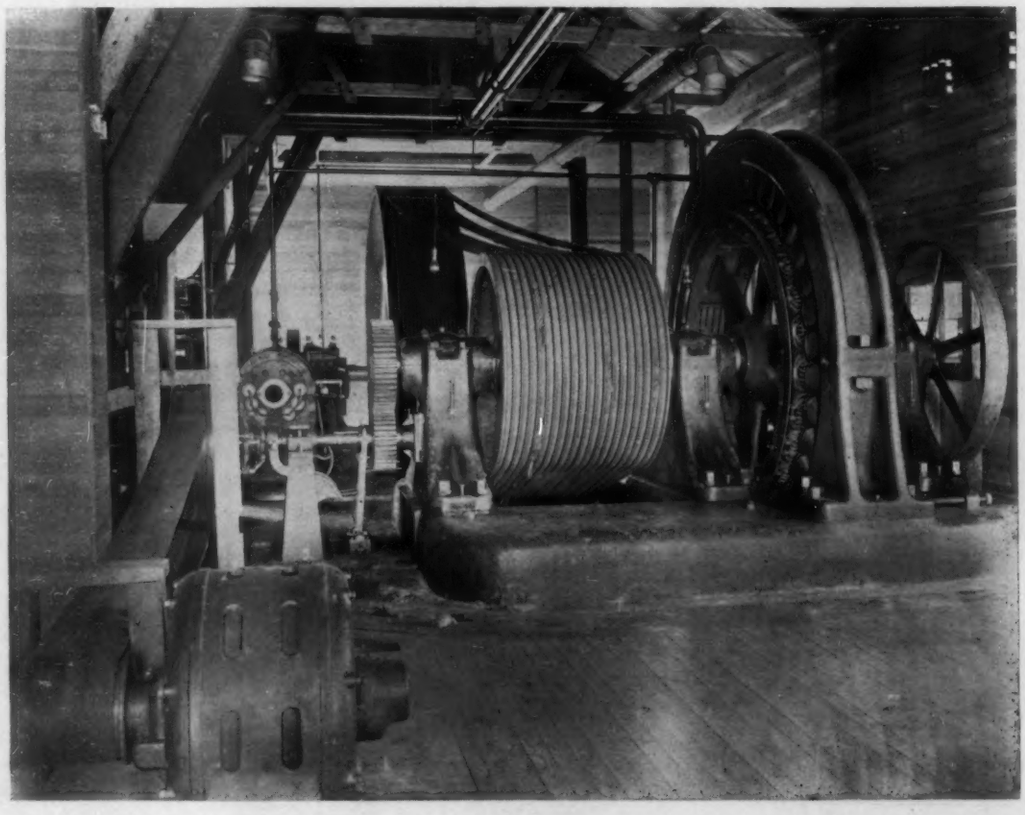


FIGURE 28.—VIEW OF 400 H.-P. SYNCHRONOUS MOTOR, DRIVING 40-DRILL COMPRESSOR AT WAR EAGLE MINE.

At the Iron Mast mine is a 75-kilowatt "S. K. C." synchronous motor, made by the Royal Electric Company of Montreal. It is a two-phase motor, with connections altered for three-phase service, and is started through an "S. K. C."

induction motor and water rheostat, both of which appear in the illustration shown in Figure 29. The water rheostat consists of three fan-shaped blades plunged edgewise into a three-compartment tank of water, thus enabling the water resistance cut into each leg of the three-phase circuit to be varied according to the depth of immersion. The 75-kilowatt motor is belted to a jack-shaft in the manner shown, which drives two double-acting compressors having a combined capacity of ten drills. This is the only Stanley equipment on the West Kootenay circuit, and its service is most reliable.

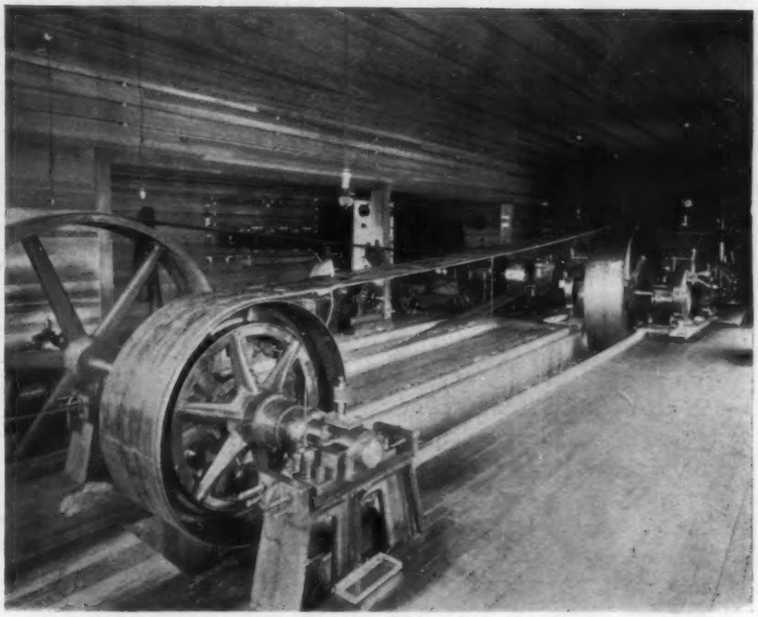


FIGURE 29.—STANLEY 100 HORSE-POWER SYNCHRONOUS MOTOR, DRIVING 10-DRILL COMPRESSOR AT THE IRON MASK MINE.

In the Big Three mine is a 75-kilowatt General Electric synchronous motor, driving a seven-drill compressor in the manner shown in Figure 30, while at the Gertrude mine is a 50 horse-power General Electric induction motor operating a hoist. The British Columbia Bullion Extraction Company has one 50 horse-power induction motor driving a rock breaker, and one 75-kilowatt synchronous motor operating all machinery about the mine, including generators for electrolytic work.

These motors, as well as all others referred to hereafter, are of Canadian General Electric manufacture. In the properties of the British-American Corporation are four 150 horse-power induction motors, each operating a double drum hoist through equipments which are in every way similar to those at the War Eagle mine. All underground work in and about Rossland is operated at 220 volts. Aside from mining work, the principle power installation is that of the general machine shop of Cunliffe & Abblett, where a 50 horse-power induction motor is installed. There are many small motors ranging from one to five horse-power in size for the furnishing of light power in different industries in Rossland.

One of the most interesting points to be brought out by the Kootenay-Rossland transmission is the demonstration of the fact that the operation of synchronous and induction motors in large units for the driving of hoists and compressors will not necessarily create serious disturbance in the voltage of the distribution circuits, provided high voltage, ample fly-wheel effect and capacity prevails. During daylight the power and lighting circuits are operated in parallel, although they are separated and operated independently from the power house by night. The War Eagle hoist, however, is operated on an independent circuit by day, but at night it is cut into the power circuit at the Rossland sub-station. The result of this arrangement is shown in the reproduction of the recording voltmeter chart shown in Figure 19, which is that of the lighting circuit. From 6:45 p. m. to 5:00 a. m. the chart shows the regulation of the lighting circuit when on an independent line from the power house. At 5:00 a. m. the War Eagle hoist is taken from the power circuit and put on an independent line to the power house and the remaining power load is coupled in with the lighting load and carried on the second line to the power house. The voltmeter curve therefore, from 5:00 a. m. to 6:45 p. m. shows the regulation of the plant when all power with the exception of that for the War Eagle hoist is in parallel with the day lighting load. The chart given is that for an ordinary day, and, indeed, the charts run so evenly from day to day that each almost dupli-

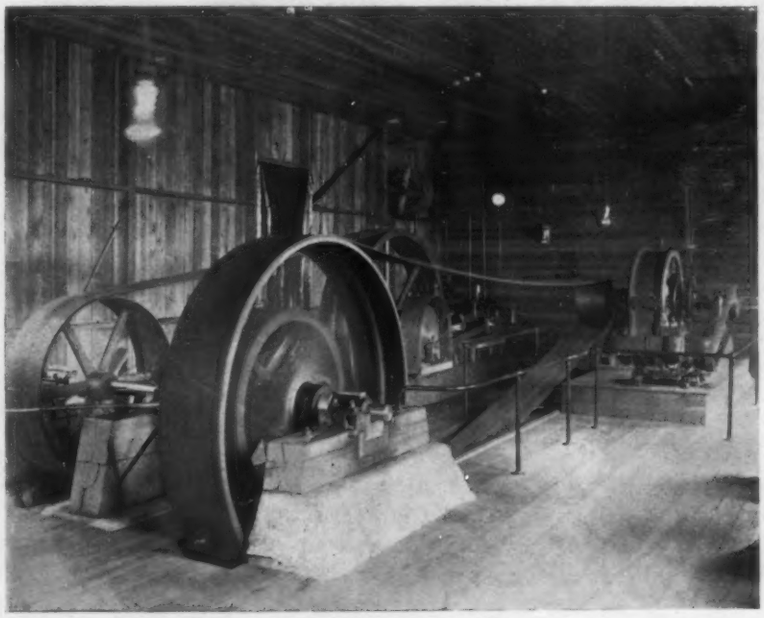


FIGURE 30.—100 HORSE-POWER SYNCHRONOUS MOTOR, DRIVING SEVEN-DRILL COMPRESSOR AT THE BIG THREE MINE.

cates the other. The day in question there were in operation from 5:00 a. m. to 6:45 p. m. three 100 horse-power synchronous motors with an average load of 280 horse-power on compressor work; five 50 horse-power induction motors with an average load of 210 horse-power on the same, 3 of which were on hoists; three 30 horse-power induction motors with an average load of 76 horse-power, and one 40 horse-power induction motor carrying an average load of 32 horse-power. The lighting load consisted of 300 horse-power, which is high in proportion to the night lighting load because of the heavy 24-hour load carried. The report from the generating station for the same day shows that the variation reached 108 amperes at 110 volts, or an approximate variation of 205 horse-power, considering which the regulation is remarkably good. The secret of this is stated to lie in always maintaining a high voltage in relation to the motor ratings, with ample generator and water wheel capacity.

The conception and commencement of the work on the remarkably interesting transmission of the West Kootenay Power and Light Company, Limited, are largely due to the efforts of Sir Charles Ross, Bart., and Mr. Oliver Durant. The charter was obtained in the name of Mr. Patrick A. Largey, president of the Center Star Mining and Smelting Company, Oliver Durant, manager, and C. R. Hosmer, manager of the Canadian Pacific Railway Company's telegraphs, and it was afterward transferred to the West Kootenay Power and Light Company. Preliminary surveys were made early in 1897, but it was in July of that year that the location of the plant was definitely settled and actual construction begun. The plans of the company contemplate the ultimate utilization of the entire three falls.

The present Board of Directors of the West Kootenay company are Sir Charles Ross, Bart., Balnagown, Scotland, President; Mr. W. M. Doull, Montreal, Vice-President; Mr. J. M. Smith, Rossland, Secretary and Treasurer; Mr. L. A. Campbell, General Manager, and Messrs. Oliver Durant, Rossland, C. R. Hosmer and Frank Paul, Montreal, and T. G. Blackstock, Rossland. The entire plant is under the personal management of Mr. L. A. Campbell, to whom great credit is also due for the able administration of the position of electrical engineer which he has filled in addition to his duties as general manager. The line was erected under the supervision of Mr. B. O. Boswell, so well known in California as superintendent of construction of the lines of the Folsom-Sacramento, Fresno, and other transmissions.

Personal

MR. A. M. HUNT has accepted the responsibilities of the general managership of the Independent Light and Power Company, San Francisco, in addition to his position of engineer-in-chief of the same concern.

MR. T. E. THEBERATH will hereafter devote his entire time to the Yuba Electric Power Company, of which he is electrical engineer, to accept which position he has resigned from the electrical engineership of the Pacific Coast agency of the Stanley Electric Manufacturing Company.

Gas

INDUSTRIAL GAS.—III.

BY FRANK H. BATES.

[THE ELLIOTT APPARATUS—CONTINUED.]

THE gas residue, sometimes termed gas rest, or portion remaining after the absorbable constituents have been removed, may consist of hydrogen, methane, and nitrogen.* The explosion or combustion tube is employed for their determination, since in their combination with oxygen there is a resulting contraction, which, together with the volume of carbon dioxide formed, affords sufficient data for the computation of the volume burned.

Operation. The gas residue is retained in the measuring burette; with the stop-cock H′ (Figure 4†) closed to the burette B and open to the horizontal capillary, adjust stop-cock M′ so that it communicates with the explosion burette, absorption tube and outlet N′. By raising the level-bottles M and P, force any air from the capillary, completely filling the entire apparatus with the exception of the measuring burette containing the gas residue, with water, when close stop-cock M′ to both burette and capillary, the outlet toward the right. Raise level-bottle N, turn stop-cock H′ so as to bring the outlet open to the capillary in the direction of the explosion burette, lower level-bottle P, open stop-cock M′ so that it makes connection between the explosion and measuring burettes (position shown in cut), and admit to the former some 15 cubic centimeters of the residual gas, by the graduations on the explosion burette. Close stop-cock H′ by bringing to the position with the outlet in the direction of the explosion burette just closed, and after waiting one minute for the walls to drain, raise level-bottle P so that the level of the contained water will correspond to that in the explosion burette, and note the reading, giving the volume of the sample of residual gas under atmospheric pressure. Since the determination of the constituents of the residual gas is by means of combustion or chemical union with oxygen, sufficient of the latter must be admitted to supply the hydrogen and methane, the nitrogen remaining inert. Hydrogen requires one-half its volume of oxygen for complete combustion, and methane requires twice its volume, consequently, with an approximate knowledge of the amounts of these constituents present, it is a simple matter to decide upon the quantity of oxygen required, taking care to admit in excess.

With but a knowledge of the kind of gas under examination, whether coal, water, or producer gas, etc., one will be sufficiently guided after a little experience. The oxygen is admitted partly as free air, (air is about 22 per cent. oxygen by volume), and partly as pure oxygen. Generally speaking, for illuminating gas the air used should equal the volume of the gas sample. This may be admitted through the stop-cock T′ at the lower end of the explosion

*Traces of carbon monoxide and ethane and their determinations will be treated under "Special Schemes" in a later issue.

†See THE JOURNAL OF ELECTRICITY, May number.

burette, but more conveniently through the capillary N′ and stop-cock M′ by expanding the gas in the explosion burette by lowering level-bottle P. After admitting the air, make connection between the end U′ of the projecting capillary and the supply of oxygen.* Open stop-cock T′, admitting sufficient oxygen to make a total gas volume of about 75 cubic centimeters, when close stop-cock T′ and raise and lower level-bottle P, causing the gas to become thoroughly mixed, also dislodging any oxygen caught in the capillary above the stop-cock T′. Wait one minute for the burette walls to drain, then measure the total gas volume under atmospheric pressure. Dislodge any water adhering to the ends of the platinum wires by tapping the tube slightly. Lower the level-bottle P as far as possible to expand the gas, thus tending to render the explosion less severe. With all precautions there is a possibility of fracture at this time; it is therefore best not to expose the eyes. Make connection to the induction coil and battery, closing the circuit, causing a spark to pass between the points of the wires, thereby igniting the gas, which gives a sharp click.

Allow the heat of the combustion to be absorbed by the circulating water in the jacket and then take the reading of the gas volume under atmospheric pressure. This, subtracted from the reading of total gas volume taken before the explosion, gives the contraction, which, for future reference, we will call C. Now raise level-bottle P, lower level-bottle M, and noting that the horizontal capillary and absorption tube are filled with water, transfer the products of combustion from the explosion burette to the absorption tube, where treatment with potassium hydroxide will absorb the carbon dioxide formed. After treatment with the absorbent, transfer back to the explosion burette, and, after waiting one minute for the walls of the burette to drain, measure, under atmospheric pressure, the amount of absorption. Let the amount, which equals the carbon dioxide formed, be called D. We now have sufficient data to determine the percentage of hydrogen and methane directly, and the nitrogen by difference.

The chemical reaction of hydrogen with oxygen is expressed by the following equation:

$$\underset{\text{Hydrogen}}{H_2} + \underset{\text{Oxygen}}{(O_2)_{\frac{1}{2}}} = \underset{\text{Water}}{H_2O} \quad \text{(Equation 1)}$$

One volume of hydrogen unites with one-half volume of oxygen, forming water, which, in changing from a gaseous to a liquid form, contracts so as to be of no appreciable volume, hence its volume may be neglected; we have then, 1 volume + ½ volume, or 1½ volumes contracting to zero volumes; or, the amount of contraction equals 1½ volumes, which is 1½ times the amount of hydrogen burned. (1½H).

The reaction of methane with oxygen is expressed by the equation:

$$\underset{\text{Methane}}{CH_4} + \underset{\text{Oxygen}}{(O_2)_2} = \underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Water}}{2H_2O} \quad \text{(Equation 2)}$$

*The oxygen may be prepared by heating a mixture of four parts, by weight, of potassium chlorate and one part of manganese dioxide, in a generator supplied for this purpose, and collecting in a gas holder in which the gas should be put under a slight pressure.

One volume of methane uniting with two volumes of oxygen, forming one volume of carbon dioxide and water. As before, the water volume is neglected, hence we have 1 volume + 2 volumes, or 3 volumes; contracting to 1 volume, or the amount of contraction equals 2 volumes, which is 2 times the volume of methane burned. ($2CH_4$). There is one volume of carbon dioxide formed for each volume of methane burned, or $CO_2 = CH_4$.

Collecting from equations 1 and 2, we have

$$C = 1\tfrac{1}{2}H + 2CH_4 \quad \text{(Equation 3)}$$
$$D = 1CH_4 \quad \text{(Equation 4)}$$

in which C = the total contraction resulting from the combustion of the residual gas, and D = the carbon dioxide formed.

C, the contraction, is known as measured in the explosion burette, also D, the carbon dioxide formed, the amount of which was determined by absorption with potassium hydroxide; substituting for CH_4 in equation 3, its value D, from equation 4, we have

$$C = 1\tfrac{1}{2}H + 2D, \text{ or, } H = \frac{C - 2D}{\frac{3}{2}} = \frac{2C - 4D}{3} \quad \text{(Eq. 5)}$$

By substituting for D in equation 4, and for D and C in equation 5, their values, the per cents of methane and hydrogen become known.

The sum total of the per cents so far determined, subtracted from 100, gives the percentage of nitrogen. An example will serve to illustrate the entire proceeding:

Analysis of Coal Gas. A two-liter bottle of water was first saturated with the gas to be examined. The level-bottles and apparatus were then filled with the prepared water, expelling all air. A little more than 100 cubic centimeters of sample gas was drawn into the absorption tube, and afterward transferred to the measuring burette, where exactly 100 cubic centimeters, measured under atmospheric pressure, was retained, the excess being expelled by filling the apparatus with water from the level-bottles.

Gas then transferred to the absorption tube, where it was treated with potassium hydroxide, the first reagent.

Gas returned to the burette, and, after waiting one minute for drainage of walls, measured under atmospheric pressure, giving a reading of 99.5. This, subtracted from 100, gave the percentage of carbon dioxide:

$100 - 99.5 = 0.5$, or, CO_2 = ½ of 1 per cent.

The absorption tube was drained of the reagent, rinsed, and refilled with water. Gas then transferred to the absorption tube and treated with bromine water, the second reagent. As soon as the absorption was complete, potassium hydroxide was added to absorb the bromine vapors formed. Gas then returned to the burette and measured under atmospheric pressure, giving a reading of 95.5. This, subtracted from the previous one, 99.5, gave the per cent. of illuminants:

$99.5 - 95.5 = 4$, or, illuminants, 4 per cent.

The absorption tube was then drained of the reagent rinsed and refilled with water.

Gas then transferred to the absorption tube and treated with potassium pyrogallate, the third reagent.

Gas returned to burette and measured under atmospheric pressure, giving a reading of 95. This, subtracted from the previous one, 95.5, gave the percentage of oxygen:

$$95.5 - 95 = 0.5, \text{ or, } O = \tfrac{1}{2} \text{ of } 1 \text{ per cent.}$$

The absorption tube was drained of the last reagent, rinsed, and refilled with water.

Gas then transferred to the absorption tube and treated with cuprous chloride, the fourth reagent. Afterwards water was added to absorb the acid vapors and wash down the curdy, white precipitate of cuprous chloride.

Gas returned to burette and measured under atmospheric pressure, giving a reading of 89. This, subtracted from the previous one, 95, gave the percentage of carbon monoxide:

$$95 - 89 = 6, \text{ or, } CO = 6 \text{ per cent.}$$

The absorption tube was drained of the last reagent, rinsed, and refilled with water.

A portion of the gas now remaining, termed the residual gas, was transferred to the explosion burette, and on measuring was found to be 18 cubic centimeters. To this was added about 15 cubic centimeters of air and then oxygen sufficient to bring the total volume to 80 cubic centimeters, all measured under atmospheric pressure. By raising and lowering the level-bottle these gases were thoroughly mixed. A slight tapping dislodged the water adhering to the points of the platinum wires. The gas mixture was expanded by lowering the level-bottle as far as the rubber tubing would permit, thereby lessening the intensity of the explosion. On closing the circuit a sharp click was heard, giving assurance that the explosion occurred.

After a lapse of three minutes, the gas was measured under atmospheric pressure, giving a reading of 49.53. This, subtracted from 80, the amount burned, gave the contraction: $80 - 49.53 = 30.47$.

The products of the combustion, or gas remaining in the explosion burette, was transferred to the absorption tube and treated with potassium hydroxide.

Gas returned to the explosion burette and measured under atmospheric pressure, giving a reading of 41.43. This, subtracted from the previous one, 49.53, gave the amount of carbon dioxide formed by the combustion of the gas residue:

$49.53 - 41.43 = 8.1$, or, the $CO_2 = 8.1$ cubic centimeters, and CH_4 present in 18 cubic centimeters of residual gas equals 8.1 cubic centimeters, since $CH_4 = D = CO_2$, by equation 4.

For the total amount of residual gas, 89 cubic centimeters, the methane would equal, by simple proportion:

$18 : 89 :: 8.1 : X$; $X = 40.05$, or, $CH_4 = 40.05$ per cent.

The hydrogen is computed from equation 5:

$$H = \frac{2C - 4D}{3} = \frac{2(30.47) - 4(8.1)}{3} = 9.51$$

or the hydrogen present in 18 cubic centimeters of residual gas equals 9.51 cubic centimeters; hence for the total volume of residual gas, 89 cubic centimeters, we have by simple proportion

$18 : 89 :: 9.51 : Y$; $Y = 47.02$, or $H = 47.02$ per cent.

All the constituents of the sample gas have now been determined, with the exception of nitrogen, which may be found by difference as follows:

CO_2	= 0.50
C_2H_4 (illuminants)	= 4.00
O	= 0.50
CO	= 6.00
CH_4	= 40.05
H	= 47.02
Total - - -	= 98.07 and

$100 - 98.07 = 1.93$, or, $N = 1.93$ per cent.

The following table of analyses serves to illustrate the wide range of work to which this apparatus is adapted:

GASES.	CO_2	O	CO	N	C_2H_4	CH_4	H
Flue Gas. (Bituminous coal)	9.65	8.55	0.00	81.80	0 00	0.00	0.00
Hoffman Oven Gas.	1.41	0.43	6.49	0.00	2.04	36.31	53.32
Producer Gas (Bituminous coal)	2.50	0.30	27.00	55.30	0.40	2.50	12.00
Producer Gas (Anthracite coal)	2.50	0.30	27.00	57.00	0.00	1.20	12.00
Water Gas	4.00	0.50	45.00	2.00	0 00	3.50	45.00
Natural Gas	0.60	0 80	0.60	3.00	1.00	72 00	22 00
Coal Gas	0.30	0 40	7.60	2.80	4 30	36.50	48.10

Properties of Gases. HYDROGEN: Symbol, H; atomic mass, 1; Valence, 1; molecular mass, 2; specific gravity compared to air, 0.0695; weight of one liter, 0.089578 grams; weight of cubic foot, 0.005592.

An irrespirable, colorless, odorless, and tasteless gas, and the lightest form of matter known, being about 14.43 times lighter than air. It is slightly soluble in water, 1.9 volumes being absorbed by 100 volumes of water. Heated to about 500° Centigrade, it is combustible, combining with oxygen with evolutions of light and heat. It produces a pale, bluish flame, which becomes bright with increasing pressure. Hydrogen in burning evolves 34,462 calories per kilogram. Cooled in boiling nitrogen to −213° Centigrade, under a pressure of 160 atmospheres, hydrogen has been brought to a colorless, transparent liquid.

The reaction with oxygen is:

$$H_2 + (O_2)_{\frac{1}{2}} = H_2O$$

Preparation. Hydrogen may be prepared by the action of zinc upon an acid, as sulphuric acid:

$$\underset{\substack{\text{Hydrogen Sulphate or Sulphuric Acid}}}{H_2(SO_4)} + \underset{\text{Zinc}}{Zn} = \underset{\text{Zinc Sulphate}}{Zn(SO_4)} + \underset{\text{Free Hydrogen}}{\uparrow H_2}$$

METHANE: Synonyms, marsh gas, fire damp, after damp, hydrogen carbide; formula, CH_4; molecular mass, 16; according to Meyer and Senbert, 15.97. Specific gravity compared to air, 0.5560; weight of one liter, 0.719 grams; weight of one cubic foot, 0.04488 pounds.

An irrespirable, colorless, odorless, tasteless gas, and is the next lightest gas to hydrogen. It is slightly soluble in water; combustible, emitting a pale, faintly luminous flame when burning in air. Mixed with oxygen in the proportions expressed in the reaction below, two volumes of oxygen or about ten volumes of air, forms an explosive mixture, often the cause of serious accidents in coal mines, where it collects, together with other explosive gases.

The reaction with oxygen is:

$$CH_4 + (O_2)_2 = CO_2 + (H_2O)_2$$

Preparation. Methane may be prepared by heating sodium acetate in presence of sodium hydroxide:

$$CO\begin{cases} CH_3 \\ ONa \end{cases} + \begin{matrix} Na \\ H \end{matrix}\Big\} O = CO\begin{cases} ONa \\ ONa \end{cases} + \uparrow CH_4$$

Sodium Acetate — Sodium Hydroxide — Sodium Carbonate — Methane

The Elliott apparatus herein described is a modification of the older form, which is similar except that it is not provided with an explosion burette and has but a two-way cock at H′, and no outlet as at N′, making it difficult to expel any air caught in the horizontal capillary. This form is made full size, the burette being graduated to contain 100 cubic centimeters, and is quite largely used.

(Continuation in next number.)

Pneumatics

LIQUID AIR AS A NEW SOURCE OF POWER.*

DURING 1894-5 the present writer prepared two articles under the title of "Engineering Fallacies" which were published in this journal, Vol. XI, pp. 273-294, and Vol. XII, p. 125. Since that time, though several new forms of what might be termed in a general way "Perpetual Motion Schemes" have appeared, none of them has seemed of sufficient importance to warrant any special notice, but in the March number of *McClure's Magazine* there is published an article entitled "Liquid Air—a new substance that promises to do the work of coal and ice and gunpowder, at next to no cost," which is so eminently calculated to mislead the general reader and even to become the basis of financial frauds, like that of the Keely motor, that it would seem a duty to draw attention to the fundamental errors in scientific principles and in statement of facts which this article contains.

This *McClure* article may be fairly considered as made up of two prominent elements or parts, one of which is the statement of certain things as facts which, as I shall presently show, cannot possibly exist and are inconsistent with other facts stated in the same article and known from other sources to exist as so stated; while the other main element consists of rather vague statements concerning general principles which, though in a general sense true, yet as here used are calculated to cover up or befog the too obvious inconsistencies of the statements of facts, with the established principles of science.

As an example of the first element, we find on page 400 as follows: "I have actually made about ten gallons of liquid air in my liquifier by the use of three gallons in my engine." This I shall presently show is simply impossible and inconsistent with data given elsewhere in this article and known to be substantially correct.

A sample of the other element is found on page 399 in the following: "That is perpetual motion you object. 'No,' says Mr. Tripler, sharply; 'no perpetual motion about it. The heat of the atmosphere is boiling the liquid air in my engine and producing power exactly as the heat of coal boils water and drives off steam. I simply use another form of heat. I get my power from the heat of the sun; so does every other producer of power."

This, while true as a general statement of what might be done on an impractical scale, is not correct as here used to imply that in his experiments Mr. Tripler actually derives or can derive any adequate amount of energy from the heat of the atmosphere, or in that sense directly from the sun. This I shall show later, but will first take up the statement that three gallons of liquid air have supplied or can supply the power to liquify ten gallons.

On pages 402 and 403 of the *McClure* article we are told that Mr. Tripler uses to make his liquid air a steam engine of 50 horse-power, and that with this he can make liquid air at the rate of 50 gallons a day. This I know from other sources is substantially correct, and means that *each horse-power in a day (say 10 hours) makes one gallon of liquid air.* In other words, one gallon for 10 horse-power hours.

It is again stated in this article, on page 405, that a cubic foot of liquid air contains 800 cubic feet of air at ordinary atmospheric temperature and pressure, or in other words, any volume of liquid air, if adequately heated, will expand 800 times in reaching atmospheric temperature and pressure. This also is substantially correct. We may remark in passing, that this is nothing wonderful, for water, when expanded into steam at atmospheric pressure, increases about 1700 times in volume, or more than twice as much as liquid air. If we apply to the above data the well known and universally accepted formula* for the maximum work done by air when expanded at constant temperature, we find that a pound of liquid air in expanding 800 times would develop about 190,000 foot-pounds of work. As a gallon of liquid air weighs about eight pounds, this would give eight times as many foot-pounds, or 1,520,000. If this work were accomplished in an hour, it would represent almost exactly ¾ of a horse-power, because one horse-power means 1,980,000 foot-pounds of work per hour, and 1,520,000 is only a trifle over three-fourths of this. From the above, it follows as a matter of *absolute certainty* that the maximum power which liquid air could develop in an *ideally perfect engine* without any loss from friction or other cause, would be *three-fourths of a horse-power for an hour for each gallon of liquid air expended.*

We have seen, however, that with his 50 horse-power plant, which on account of its size should operate with considerable efficiency, Mr. Tripler *makes only one gallon* of liquid air with *10 horse-power hours.* In other words, he requires to make a gallon of liquid air *12 times as much power* as a gallon of liquid air could *possibly develop in an ideally perfect engine.*

In face of this, how supremely absurd is the statement that with a little engine such as the pictures and descriptions in the *McClure* article show, lacking all conditions for efficient working, Mr. Tripler can make 10 gallons of liquid air by the use of three.

Turning next to the statement about using the heat of the atmosphere to develop mechanical energy or work, let us put this to the test of a quantitative example.

Assume the temperature of Mr. Tripler's laboratory to be 70° F., and that he has an abundant supply of water at 50° F. These will be, of necessity, the limits of work he can get out of the atmosphere, because any lower temperature is only secured by doing work and so expanding energy which will be at least equal to the power obtainable from the use of such lower temperature. All the work that can be obtained *for nothing* is that which nature will freely give in the warm air and cool water, supposing both to be supplied freely without charge.

The 20° F. which we may assume as being possibly taken out of the air by the cool water, will represent the maximum gift of nature in this shape of "power costing nothing." Now 42 British thermal units, or pounds of water changed 1° F. per minute, will represent one horse-power, and as the specific heat of air is about one-quarter that of water, we would need four times as many pounds of air to produce the same effect. This would call for 168

(Continued on page 99.)

*Prof. Henry Morton, Ph. D., LL. D., Sc. D., in *Stevens' Indicator.*

*$W = p_2\, v_2$ hyp log $\frac{v_2}{v_1}$

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EDITORIAL.

THE WRATH OF THE PEOPLE.

Whether deserved or otherwise, it is undoubtedly true that, perhaps with the single exception of street railway companies, gas companies constitute the class that is more reviled by the public than any other line of corporations catering public commodities. Electric lighting interests have, as a rule, been far less under the ban of common censure than have their gas cousins, probably because of the true competition which electricity has afforded, but when the quondam gas company and the likewise quondam electric company of a community bury their animosities, unite and deport themselves with airs of monopolistic arrogance—buy legislative bodies, prevent the granting of franchises to competing companies, and maintain extortionate rates—then the public at last ceases to forbear longer and the stock market records indelibly the rash consequences of their misdoings. For the companies to rebuff these criticisms with words or actions bespeaking a Vanderbiltian condemnation of the public is at least impolitic; to dismiss them as idle riff-raff is puerile; to placate them with ne'er to be fulfilled promises hastens the day of reckoning, and to rely implicitly on the power of money is a species of self-incrimination not to be always misunderstood.

Patient and long-suffering though the public may be, it is fatal to not remember that it has its last straw of endurance and that when it has been reached the distress of the over-burdened community will be reflected immeasurably, though indirectly, on the earning and market values of the corporations. Among these penalties are, briefly, the perennial agitations of socialistic natures; the organization of competitive companies, some being *bona fide*, but many being "sell outs," and the ever growing cry for the municipal ownership of quasi-public utilities, all of which owe their motherhood to conditions first voiced in the clamor of denunciation heaped upon unpopular corporations.

Merchants attain success best through honesty and fair dealing which induce the prime-essential popularity requisite to the upbuilding of a fortune. Are quasi-public corporations inherently so constituted that they can not appreciate these truths? We judge not, although the list of evident *incorrigibles* is of appalling length.

DETERMINING WATER WHEEL EFFICIENCIES.

Away back in 1786, James Rumsey, who was a friend of Robert Fulton long before the latter had made his name immortal through the invention of the steamboat, and from whom, indeed, Fulton is said to have gotten the idea of steam navigation, propelled a quaint boat on the Potomac River through the instrumentality of a powerful steam pump which forced water through a battery of tubes placed in the stern of the vessel. The streams of water, striking against the surface of the river, shoved the boat along against the current of the stream at a speed of five miles an hour.

Here in the closing and, consequently, most enlightened year of the nineteenth century, hydraulic engineers the world over place the buckets of a tangential wheel directly in a jet of water close to its orifice and then consider the spouting velocity of the jet as unaffected by the presence or action of the buckets. If this reasoning were true, Rumsey's boat would have been incapable of self-propulsion. The two conditions, though reversed, are parallel; for while in each case the energy of the jets is converted into motion, work is performed, so to speak, at the sacrifice of velocity.

The question which naturally arises is: Why make the theoretical spouting velocity of the jet the basis of determination of water wheel efficiency when its actual spouting velocity can by no means equal the theoretical spouting velocity?

It would seem that an investigation of this subject would at least result in the re-determination of some of the water wheel efficiencies that have become accepted in hydraulic engineering practices.

Passing Comment

An Editorial Review of Current Events and Contemporary Publications.

QUALIFICATIONS OF AN ENGINEER'S ASSAILANTS.

Even the lay press has periods of sanity in discussing matters electrical—at least one San Francisco daily, *The Examiner*, has given evidence of realizing that this is a day of specialists, and that the opinion of an engineer who has attained eminence in his profession is not to be blown aside lightly as by supervisorial verbiage or the gust of wind from a flying beer cork, for thus does *The Examiner* discuss the reception given by the honorable Board of Supervisors of the City and County of San Francisco to the report of A. M. Hunt, on the cost of a plant for lighting the streets and municipal buildings of the city:

The friends of the gas combine are badly shaken up by Engineer Hunt's estimate of cost and operation of a municipal plant capable of lighting the streets and public buildings. The one answer that they have been able to suggest is, "The figures are wrong."

That able expert, Supervisor Collins, who gets his electrical experience as the secretary of a hay and grain establishment, says, "I will show that Phelan's (Hunt's) figures are far from correct."

Supervisor Kalben, who gets his knowledge of the electrical business by his connection with the California Bottling Company, says, "I know it can't be had for the sum Hunt says."

Supervisor Attridge, who has qualified himself by being a shoemaker to pass on Mr. Hunt's report, says, "We (Collins and myself) are preparing a report which will deal fully with the question," and some remarkable estimates may be expected.

Meanwhile, the Mayor stands by Engineer Hunt's report, and apparently with good reason. It is true that Mr. Hunt is neither a bottler nor a shoemaker, and has not had the advantages that come from running a hay and grain business. But he is a graduate of the United States Naval Academy, a specialist in electricity, the electrical expert of the Midwinter Fair, the consulting or superintending engineer for most of the big electrical works of the State, and has high standing in his profession. When he says that the plant can be set up for $459,005, and can be operated for $170,838, including labor, materials, depreciation and repairs, there is good ground for supposing that his figures are correct.

* * *

AN ENGLISH METHOD OF DRYING TRANSFORMERS.

Mr. Hamilton Kilgour, in a paper read before the Northern Society of Electrical Engineers,* states that transformers of the 650-watt size, or thereabouts, used for arc lighting and placed in the bases of lamp posts, and which have given trouble from dampness, have been successfully treated by passing short lead covered cables through the glands and connecting them to the primary and secondary terminals in the manner to be described. These glands and all openings into the transformer case, except the door to the fuses, are sealed up; the transformers are then taken in batches into a hot dry room where the primaries are connected in parallel to a 100-volt circuit, and the secondaries in series to a low resistance, by which the secondary current can be varied from about eight to fifteen amperes as desired. Pots of calcium chloride are inserted through the fuse doors, which are then sealed up. The transformers are run in this way for about a week, the calcium chloride being changed frequently at first, and the fuse door resealed after each charge. Toward the end of the week very little water is found to remain in the transformers, and at the end of this preliminary run each transformer is given a new quantity of calcium chloride and is finally sealed up. They are then run individually for some hours, or perhaps a day or two, with their primaries connected to a 2000-volt circuit and their secondaries to arc lamps; the primary is also flashed to the case with 2000 volts. Larger transformers are dried in a somewhat similar way, except that they are usually dealt with individually and have their secondaries connected through resistances to a low pressure circuit and their primaries to lamp loads.

In marked contrast to this method is the one which is almost universally used in this country, namely, simple baking in the dry kiln until the transformer has been brought up to an insulation resistance of at least one megohm for each 1000 volts to be applied under working conditions.

*Reprinted in *The Electrician*, Vol. XLII, No. 6, June 2, 1899.

Transmission

CALCULATING TRANSMISSION CONDUCTORS.*

BY PROF. GEORGE FORBES, F. R. S., M. I. C. E.

UP to the present date financial men have not realized the value of long distance transmission. Engineers, too, have been so much engaged with electric lighting and traction that few have devoted much time to its study. The last nine years of my life have been devoted almost entirely to electric transmission and the last four years to very distant transmission. At present there exist no printed tables for facilitating calculations, such as civil engineers possess in other branches of the profession. In the case of electric transmission, every engineer must prepare his own sets of tables and curves to work from. I have been compelled to work these out for myself in various units, hence you will believe that I possess a mass of tables and curves, and these might be worth publishing if the time had arrived, which is not perhaps yet. During these years, however, my methods have become so simplified that I venture to bring to your notice one curve in relation to the one special question of efficiency and cost of transmission lines. It is so simple in its present form through a gradual evolution that I cannot help thinking that it may be of use to others.

In transmission schemes the cost of copper becomes so all-important, when dealing with long distances, that it helps more than I can tell you to have simple means for estimating even roughly the cost and efficiency under various conditions. I feel some diffidence in laying before you these methods, because there is nothing new in the results, and all the results can be obtained by the ordinary methods. They have, however, been invaluable to myself. These methods are particularly useful for getting out preliminary estimates quickly.

Here let me say that in all preliminary work on the cost of long conductor lines I never take notice of the resistance of the conductor, nor of the value of the current. I deal only with the current density and loss of volts. It is the same thing under a different name. But it is what you want.

Again, I never use for calculations for my own use the efficiency of the conductor system. It is far more convenient to use the inefficiency or the reciprocal of the efficiency, which is also the horse-power put into the generating end of the line to deliver one horse-power at the other end.

I suppose everyone present is aware of the fact that if you had a case where the power cost absolutely nothing, you would use the least copper and have the cheapest arrangement, with an inefficiency of two; *i. e.*, an efficiency of 50 per cent., or two horse-power generated for each horse-power delivered. If you make the current density either greater or less than what is required to produce this inefficiency, then you have to use more copper to deliver the same quantity of power. This is a point which in a general way is appreciated by the business man who is not an electrician, as has been already stated.

Figure 1 shows this very well, and a study of it is interesting. We see that the copper required to transmit one horse-power 100 miles at an initial pressure of 10,000 volts, with continuous current, falls with the increase of density until the efficiency is 50 per cent., and then rises. This figure shows the weight of copper required per horse-power delivered at a distance of 100 miles at 10,000 volts. It is drawn for the simplest case of continuous current, to which corrections only for temperature and sag have to be made. It is equally applicable to a single-phase or two-phase alternating transmission to 100 miles at 10,000 effective volts, or at 5000 effective volts from any wire to the middle of the electric system, or to three-phase transmission to 100 miles at 5000 effective

*Excerpt from a paper read before the Society of Arts, London.

volts from any wire to the middle of the electric system. But with alternating current corrections must be made for self-induction and capacity. The same remarks apply to the meaning of the voltage of the line in all the curves and tables referred to. They are worked out for continuous current, and for any other system the engineer must add the usual corrections.

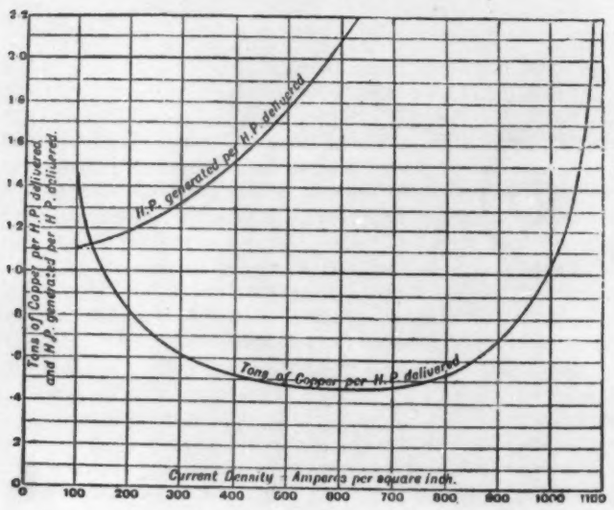

H.P. generated per H.P. delivered
Tons of Copper per H.P. delivered
Tons of Copper per H.P. delivered and H.P. generated per H.P. delivered.
Current Density = Amperes per square inch.

FIGURE 1.

Another curve may be drawn showing the inefficiency at each current density. This curve constantly rises; *i. e.*, the greater the current density, the greater is the inefficiency.

Now from these two curves we can deduce a third curve, which is the one I find which gives one in a few minutes all the main facts one wants for any horse-power to be delivered to any distance at any initial volts.

The curve gives the tons of copper per horse-power delivered at 100 miles with 10,000 volts continuous current, in terms of the horse-power generated per horse-power delivered.

Measuring along a horizontal line you get the inefficiency, *i. e.*, the horse-power generated for each horse-power delivered; and measuring vertically, you get the corresponding tons of copper required for each horse-power delivered at a distance of 100 miles. The curve is also marked with figures to show the current density in amperes per square inch section of copper.

I never travel a day without this curve in my pocket. The curve is correct for 100 miles and 10,000 volts or for any other case where volts equal 100 times the mile. The curve shows you, for example, that for an inefficiency of 1½ you require a current density of 387 amperes per square inch, and .55 ton of copper. And thus current density and weight of copper per horse-power is the same whether you use 10,000 volts at 100 miles or 100 volts at one mile.

For any other volts and distances in miles, V and M, you divide the volts by the miles and get $\frac{V}{M}$; then $\frac{V}{100M} = D$, the multiplier for the current density, and $\left(\frac{V}{100M}\right)^2 = T$, the divisor, for the tons of copper per horse-power.

As an example, 15,000 volts and 300 miles. Here

$$D = \frac{15{,}000}{100 \times 300} = \tfrac{1}{2}.$$

Hence, for an inefficiency as above of 1½, the current density will be ½ × 387 = 198. The tons of copper per horse-power will be

$$\frac{\cdot 55}{(\tfrac{1}{2})^2} = 2.20 \text{ tons.}$$

Now let me show you another use of the curve. Suppose we capitalize the cost of running the generating station, and add to it the cost of the generating works, and divide by the horse-power, we have then the capitalized value of one horse-power generated; I will call it for short the value of one horse-power generated. We also know the cost of one ton of copper. Divide the value of the horse-power by the value of the ton of copper, and draw a line across the axes so that it cuts the axes in that ratio. Draw a line parallel to this and touching the curve. This gives you, according to Lord Kelvin's law (as modified by Ayrton and Perry), the point of maximum economy, giving directly the inefficiency, the tons of copper per horse-power, and the current density. Thus on the curve two examples are shown, one where the value of one horse-power is four times that of a ton of copper. In this case the greatest economy is got by an inefficiency of 1.18, a current density of 180 amperes per square inch, and 0.91 tons of copper per horse-power delivered at 100 miles distance, the initial pressure being 10,000 volts.

Another example is shown on the curve where the horse-power is one-fifth of the cost of a ton of copper.

The resulting values are seen directly to be: Inefficiency = 1.58; current density = 420; copper = 0.51 tons. To do this for other values of T $\left[T = \left(\frac{100M}{V}\right)^2\right]$ you must divide the value of the horse-power by T. Measure this distance vertically by the unit on the vertical scale, or by fractions of these units, and measure the cost of a ton of copper horizontally by the unit on the horizontal scale or by the same fraction as before of that unit. Join the two points by a line and draw a parallel line touching the curve at the point of maximum economy.

You will see how valuable such a curve must be for obtaining the very information that an engineer requires in his first examination of any project. But we can do more than this. Divide the tons of copper per horse-power by 18 times the distance in miles, and you get the sectional area in square inches of the conductors (go and return) per horse-power. Multiply this by the total horse-power to be delivered and you get the size of your con-

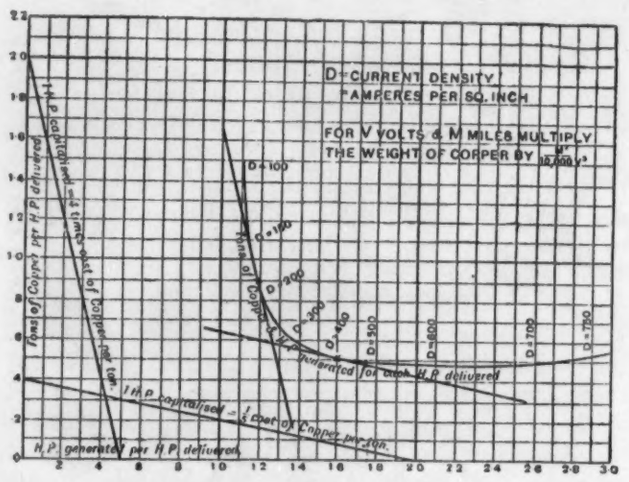

D = CURRENT DENSITY = AMPERES PER SQ. INCH
FOR V VOLTS & M MILES MULTIPLY THE WEIGHT OF COPPER BY M²/18,000 V²
1 H.P. capitalised = 4 times cost of copper per ton.
Tons of Copper per H.P. delivered
H.P. generated per H.P. delivered.
1 H.P. capitalised = ⅕ cost of Copper per ton.

FIGURE 2.

ductors. Remember that this is all worked out for *continuous current*, and must be corrected for other systems as well as for temperature and sag.

Some people prefer to work by tables instead of by curves, so I will put down the readings of the curve which we have just been discussing. For ordinary work the following is sufficient:

Inefficiency	Tons Copper per HP.	Current Density		Inefficiency	Tons Copper per HP.	Current Density
1.20	.86	190		1.70	.49	475
1.30	.66	266		1.80	.48	510
1.40	.58	330		1.90	.472	545
1.50	.55	387		2.00	.470	574
1.60	.51	432				

In most practical cases, however, the economical inefficiency

for long distance transmission lies between 1.20 and 1.50. The following table gives closer values over this range:

Inefficiency	Tons	Density	Inefficiency	Tons	Densisy
1.20	0.86	190	1.36	0.60	306
1.22	0.80	207	1.38	0.59	319
1.24	0 76	221	1.40	0.58	330
1.26	0.72	236	1.42	0.57	342
1.28	0.69	250	1.44	0.56	354
1.30	0.66	266	1.46	0.55	365
1.32	0.64	279	1.48	0.54	376
1.34	0.62	292	1.50	0.53	387

From either of these tables, having given the inefficiency, to get the density for any volts and distance, multiply the above value by $\frac{V}{100M}$, and to get the tons of copper divide the above value by $\left(\frac{V}{100M}\right)^2$

This little table enables us then, with a very simple piece of arithmetic, to get the result for any case that may arise, sufficiently close. But in actual practice I find it far more useful to have the table extended in such a way that an approximate result may be arrived at without any calculation.

Three tables are here given. The first gives a reference letter for any volts and distance. In the second and third tables the results we want are found under that reference letter. The second table gives the tons of copper per horse-power delivered, and the third gives the current density for any inefficiency that we may select.

TABLE I.—DISTANCE OF VOLTS.

	Virtual Volts between Wires.					
One or two-phase.....	5000	10,000	15,000	20,000	25,000	30,000
Three-phase.....	4325	8,650	12,975	17,300	21,625	25,950
	Distance in Miles.					
A.....	12.5	25	37.5	50	65.5	75
B.....	25	50	75	100	125	150
C.....	37.5	75	112.5	150	187.5	225
D.....	50	100	150	200	250	300
E.....	62.5	125	187.5	250	312	375
F.....	75	150	225	300	375	450
G.....	87.5	175	262.5	350	437.5	525
H.....	100	200	300	400	500	600
K.....	150	300	450	600	750	900

TABLE II.—TONS OF COPPER PER HORSE-POWER DELIVERED.

Inefficiency	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
A.....	.0537	.0412	.0362	.0344	.0319	.0306	.0300	.0295	.0294
B.....	.2150	.1650	.1450	.1375	.1275	.1225	.1200	.1180	.1175
C.....	.4837	.3725	.3262	.3094	.2869	.2756	.2700	.2655	.2644
D.....	.8600	.6600	.5800	.5500	.5100	.4900	.4800	.4720	.4700
E.....	1.344	1.031	.9062	.8594	.7969	.7656	.7500	.7375	.7344
F.....	1.935	1.499	1.305	1.237	1.148	1.102	1.080	1.062	1.058
G.....	2.634	2.020	1.776	1.684	1.562	1.504	1.470	1.446	1.439
H.....	3.440	2.640	2.320	2.200	2.040	1.960	1.920	1.888	1.880
K.....	7.740	5.940	5.220	4.950	4.590	4.410	4.320	4.248	4.230

TABLE III.—CURRENT DENSITY.

Amperes per square inch.

Inefficiency	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
A.....	760	904	1,320	1,448	1,728	1,900	2,040	2,180	2,296
B.....	380	452	660	724	864	950	1,020	1,090	1,148
C.....	253	301	440	515	576	633	680	727	765
D.....	190	226	330	387	432	475	510	515	574
E.....	152	181	264	310	346	380	408	437	459
F.....	127	151	220	258	288	317	340	363	383
G.....	108	129	188	221	246	271	292	311	327
H.....	95	113	165	193	216	237	255	272	287
K.....	63	75	110	129	144	158	170	182	191

RULES FOR USING THE TABLES.

Rule 1.—*To find the reference letter.* In Table I, in the column referring to the volts generated, find the approximate distance of transmission in miles. The capital letter at the beginning of the line in which this is found is the reference letter.

Rule 2.—*To find the tons of copper per horse-power delivered.* Look along the row in Table II referring to the reference number, and tons of copper are there given for each inefficiency. The inefficiency being the horse-power generated to deliver the horse-power at the distant point.

Rule 3.—*To find the current density.* Table III gives this in amperes per square inch in the row corresponding to the reference number, and in the column corresponding to the inefficiency chosen.

Rule 4.—*To find the economical conditions of working* (Kelvin's law). Divide the capitalized value of one horse-power by the cost of one ton of copper. Divide this by 10 and call it q. In Table II look along the row corresponding to the reference letter until the difference between successive numbers is approximately q. The number at the head of that column is the economical inefficiency, the tons are also then given, and the current density is obtained directly in Table III.

Rule 5.—*To find the total section (go and return) of all the transmission conductors.* Multiply the tons per horse-power by the total horse-power, and divide by 18 times the distance in miles. This is the result in square inches. Dividing this by the number of conductors gives the sectional area of each.

I trust that all here present who are not engineers realize now that the cost of transmission of electric power to a distance is a pure question of balancing expenditure and profits. By the methods now described, or by the ordinary methods, there can be no question as to the cost of the work. The only point, in fact, affecting the cost which has been left to the choice of the engineer is the electric pressure to be used, and every engineer in reporting on a scheme generally gives his reasons for selecting the pressure. In old days the highest pressure for which we could get a guarantee from contractors was used. But the expense of insulation was increased so much with increase of pressure that now, as at Rheinfelden, we work to that pressure which is the most economical. Manufacturers will now guarantee any pressure if you will pay for it.

Having now determined with sufficient accuracy the cost of the works and their maintenance, annual expenses and interest on mortgage, the next thing is to see (or perhaps this ought to be the first matter attended to) what return can be obtained for the power delivered to a distance. It is then for the purely financial men to say whether the profits to be derived are worth the venture.

LIQUID AIR AS A NEW SOURCE OF POWER.

(Contined from page 95.)

pounds of air changed 1° F. If, however, the air is changed 10° F. in place of 1° F., we need but $\frac{1}{10}$ or 8.4 pounds of air parting with 20° F. each minute, to give us one horse-power at 70° F. For "round numbers" let us say 8 pounds. Now a pound of air has a volume of about 13.3 cubic feet. Call this also "for round numbers" 13 cubic feet; then 8 pounds of air would be about 104 cubic feet, and this volume of air would have to part with its 20° F. heat each minute to the apparatus, in order to develop *one* horse-power. For a 50 horse-power engine 50 times as much air would be required, or 5200 cubic feet each minute; this would be the contents of a room 26×20 feet on the floor and 10 ten feet high which would have to be drawn through the apparatus each minute in such a way as to completely yield its 20° F. between 70° F. and 50° F. What sort of a boiler or heat-absorbing apparatus can we imagine which would absorb from air, at 70° F., 20° F. of its temperature while the said air was passing through it at the rate of 5200 cubic feet a minute? It would surely need to be "as big as a house," to use a familiar phrase.

This also, be it remembered, makes no allowance for loss by friction, eddy currents and the like, which would be enormous, nor for the power to put this air in motion.

Obviously such a machine would be simply huge in size, and indeed the friction involved in it would probably use up a large part of the power it could develop.

Suppose, however, that it could be built and operated in place of Mr. Tripler's 50 horse-power steam plant. Its entire output

would be 50 gallons of liquid air a day, and this, as we have seen, could only develop in an ideally perfect engine ¾ horse-power for an hour for each gallon, or 3¾ horse-power for a day of ten hours! This does not look as if heat obtained from the atmosphere and operating an engine by aid of liquid air was likely to become a dangerous rival to the coal mine.

On page 402 of the *McClure* article it is stated that Mr. Tripler makes his liquid air at a cost of 20 cents a gallon. We have shown above that the maximum power obtainable from this liquid air, by heating it to ordinary atmospheric temperature, is ¾ of a horse-power-hour. This, at 20 cents, would be vastly more expensive than power derived from an ordinary steam engine, whose cost ranges from less than one cent per horse-power-hour under the best conditions, to three or four cents, where a profit is included, or the conditions are less favorable.

The really difficult thing to explain in connection with this *McClure* article on Mr. Tripler and his liquified air, is how those concerned in its publication (being, as I do not doubt, honest men) can be deceived, or have so deceived themselves, as to make and repeat such obviously impossible statements.

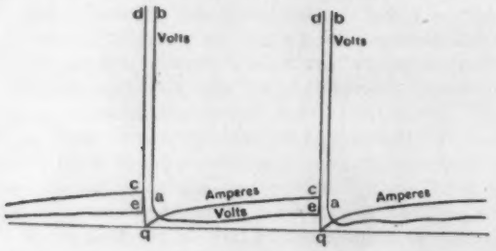
I could give from my own personal experience many like examples, but have said enough for the present to make it evident that what is claimed in this *McClure* article for liquid air as a new source of "power which costs nothing," is not founded on fact, but is probably the result of some oversight in observation or calculation not inconsistent with honesty of intention.

Physics

THE WEHNELT ELECTROLYTIC INTERRUPTER.*

BY A. BLONDEL.

THE action of the curious Wehnelt interrupter, recently presented to the Académie by M. D'Arsonval, has not yet been fully explained. It has been well established by experience that the essential condition for its oscillatory working is that the circuit be inductive. Without self-induction, the interrupter immediately stops working, the anode gets red, and a very weak current passes continuously. The self-induction of the coil, or a supplementary inductive coil suffices to produce the phenomenon, and the frequency of the latter may be varied from one to several thousands per second by varying the inductance. One may, therefore, think, with the numerous writers who have already expressed their opinion, that it is a question of resonance between



the self-induction and the capacity of the condenser formed by the polarized anode. This capacity may, for instance, reach one or two micro-farads with a platinum wire 10 millimeters long and 0.5 millimeters diameter.

But this interpretation, based on the hypothesis of sinusoidal variations for alternating currents, would not explain how the increase of electromotive force, working on a circuit of invariable composition, can increase the frequency. Neither does it seem to be confirmed by a direct study of the current curve. For example, the curve in the figure, copied from curves of current and electromotive force taken by means of my 5000 period oscillograph, by MM. Duris, Farmer, and Tchernosbitoff under my direction, indicates a single oscillation. The experiment was made at 40 periods, with a self-induction of from 0.2 to 0.3 henry in series with the interrupter. The latter had a wire similar to that already referred to. The pressure of the battery was 33 volts, the current five to six amperes; the pressure at the terminals of the cell increased to 75 volts. The figure shows that the current is first established as in all inductive circuits; the electrolysis continues to increase until the production of the gaseous envelope around the anode, then directly it is completed there is a sudden interruption of the current, and, at the same time, an enormous increase in voltage, projecting the spot outside the field of vision. Then both the current and the pressure resume their initial values and the action begins again. The precautions which we have taken to give to the circuit a slower proper period than that of the oscillograph, permits us to think that these indications may be relied upon.

Under these conditions the phenomenon of interruption only occasions one single aperiodic impulse. The energy $\frac{1}{2}LI^2$ accumulated in the self-induction, and liberated by the interruption of the current, causes the condenser formed by the polarized anode in the electrolyte to be charged at high potential. This condenser destroys itself by discharging in an arc which is formed between the platinum and the electrolyte, and drives away the dissociated oxygen. The anode is therefore immediately freed from gas, and is again in contact with the liquid which condenses the vapor, if any remains, and permits the current to flow again immediately. This action may be approximately compared with that of a hydraulic ram or a pulsometer. This explanation allows one to understand the necessity of a certain proportion between the self-induction and the anode without it being necessary to liken the phenomenon to a true resonance. One understands also why the employment of a high voltage, which increases the rapidity of the electrolysis, can increase the frequency. Finally, the form of the volts curve suffices to explain the large increase of the mean pressure at the terminals of the cell, pointed out by MM. Wehnelt and Pellat. The oscillograph used did not lend itself to an examination of the action at high frequencies, but one may fairly believe that the phenomenon preserves the same character whatever the frequency. The explanation which I have proposed may, therefore, be general.

*From the *Comptes Rendus*, April 4, 1899.

The forthcoming Mechanical and Electrical Vest-Pocket Manual compiled by Sidney Sprout, the well-known electrical engineer, will contain 204 pages of tables and data treating on electricity, steam, power, street railway, and many other subjects, and will be of almost indispensable value to engineers and others. The book will be 2¾ by 5½ inches, handsomely bound in leather, with gilt edges and round corners, and will sell for $1.00 per copy, postpaid. For further information, address Sprout & Stevens, 519 Emma Spreckels Building, San Francisco, Cal.

TABLE OF CONTENTS.

Illustrated articles are designated by an asterisk (*); Editorials by a dagger (†); Passing Comment by a double dagger (‡), and Industrial by a section mark (§).

Gas
Industrial Gas—III, by Frank H. Bates..... 92

Hydraulics
†Determining Water Wheel Efficiencies..... 96

Miscellany
‡An English Method of Drying Transformers..... 97
‡Qualifications of an Engineer's Assailants..... 96
†The Wrath of the People..... 96

Personal
..... 92

Physics
*The Wehnelt Electrolytic Interrupter, by A. Blondel..... 100

Pneumatics
Liquid Air as a New Source of Power..... 95

Transmission
*Calculating Transmission Conductors, by Prof. George Forbes, F. R. S., M. I. C. E..... 97
*The Kootenay-Rossland Power Transmission, by Geo. P. Low, —Concluded..... 85